# Ultrasonic Processing Methodologies with Alternative Thickness Computation for Massive Corrosion Mapping Tests

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**Abstract.** Large scale Automated Ultrasonic Testing (AUT) has been used in the industry in the last years with increasing field of application. The size and scope of such tests renders the use of computers, dedicated software and heavy post-processing necessary even for plain thickness mapping for material loss due to corrosion and erosion in metals. Massive tests with millions of measured points on large structures are commonplace. In the present work the conditions affecting the AUT data are discussed which are more complex and varying for such tests. The present work describes new methodologies for corrosion mapping data management and treatment with emphasis in heavy post-processing and the use of filtering concepts for data validity decisions migrated from other Non Destructive Testing (NDT) Methods. In addition to that, presents alternate methodologies for the measurement of thickness and degree of deterioration in poor and varying surface conditions. The application of such techniques to actual tests is discussed along with the relative advantages in various aspects of its application.

## Introduction

Ultrasonic Testing (UT) is one of the oldest and most widely used Non Destructive Testing (NDT) methods. The basic principle of UT is the use of ultrasound waves propagating and being reflected at geometric discontinuities or boundaries in a material. The last years, applied research in field application of UT, focuses simultaneously in two main areas, i.e. emerging ultrasound testing techniques[1] (Time of Flight Diffraction, Phased Array, Guided Waves) and Automated Ultrasonic Testing (AUT).

In the majority of industrial applications, manual-contact UT testing is performed, resulting in measurement of a limited number of points on a structure or part. In recent years, Automated Ultrasonic Testing (AUT) has been applied whenever, detailed inspection of critical structures or components, e.g. in nuclear power plant, was required. In addition AUT has also been applied to other fields such as the Process or Production Industry. Typical industrial applications are corrosion mapping of storage tanks, pressure vessels and pipes as well as on line testing for lamination and inclusions detection in plates and pipes during manufacturing.

The increased use of AUT was driven by two factors. From the one side the industry need for cost effective maintenance and increased service life by means of fitness for service has made the use of AUT advantageous and meaningful in combination with the lowered cost provided with new equipment and the short time for such a test to take place. From the other in the modern AUT systems the electro-mechanics of components have evolved and can be transported easily forming a very mobile and versatile system. In addition to that, the improvements in the hardware and software of such a system have given solutions to problems that seemed almost impossible in the past. Modern AUT systems can obtain hundreds of thousands readings (e.g. thickness measurements) in a single eight hour shift usually covering the entire required surface of a medium sized vessel.

The transition from the traditional manual UT inspection to massive tests with millions of measured points on large structures has solved many problems but has also created new challenges. In the present work the conditions affecting AUT data, which are more complex and varying for such tests, are discussed. The present work also describes new methodologies for corrosion mapping data management and treatment with emphasis in heavy post-processing and the use of filtering concepts for data validity decisions migrated from other NDT Methods. In addition to that, presents alternate methodologies for the measurement of thickness and degree of deterioration in poor and varying surface conditions. The application of such techniques to actual tests is discussed along with the relative advantages in various aspects of its application.

## Automated System Description

There are several AUT systems on the market that can perform either fully automated scanning or manually assisted. The hardware has variations in the design but in general such a system consists of one or more ultrasonic transducer, a 1/2/3 axis motion system or encoders to trace a moving probe (even in 3D in some cases), a pulse generation and A/D receiver sub-system, a motion control sub-system and either dedicated digital circuits that collect and process information (A-Scans, Gate values etc) during the scanning or normal computers that control the entire system with appropriate software. Modern AUT systems can data log thickness, amplitude and A-Scans from several gates. Multi-channel systems can do this for more than one probe and there are purpose built systems with ten or more sensors that scan for example parts on a production line.

The software[3] that is normally used to control the system has the task to allow the user to setup the UT system (gain, delay, gates etc), control the motion or the probe, encode its position, collect the information from the A/D system, display the data on a screen during the test as A/B/C-Scan plots (real-time) and store all data so that it can be used later and kept for a permanent record if required. The data acquisition software may also have some capabilities for analysis of the results such as statistics and images.

The amount of data collected make reporting a significant task for AUT tests. Recently special software[2] was developed with the task of re-processing the data and doing analysis for producing reports that are meaningful and easy to understand. The need for more complex analysis is also required in order to have a better representation of the results and remove uncertainties.

## Large Scale AUT Thickness Measurement Challenges

AUT systems measuring thickness are based on automatically moving a UT probe over a surface and collecting data at each predefined position. This is effectively equivalent to the grid that is usually drawn on a small area of a structure where thickness measurements are taken manually. However in the AUT case, the step can be very small and the speed at which measurements are taken is high. It is common to use the squirter technique with water as coupling between the UT probe and the material to be measured. The motion itself may cause some problems which are minimized by correct mechanical design and fast electronics. For example, the motion of a probe and the motors may cause vibration which can affect the position of the probe relative to the surface. Some systems do not address this issue at all and others can provide special hardware that ensures correct position. In addition the moving squirter can cause problems to the water stream that is used to transmit the ultrasonic wave thus reducing the amount of energy being transmitted in the material. This may cause loss of back-wall echo or, in extreme cases, general loss of signal.

The AUT system being a complex device requires in depth training of the operator in order to adjust or correct the system so as to provide the best performance. Another important issue which can cause uncertainty to the test is that the squirter technique on a moving device does not provide a clearly defined “0” point at the front-wall (probe face) where measurement starts. Thus the measurement start is floating, depending on front-wall echo and can be measured from the front-wall flank. Although this is a documented and proven technique which is included in international standards[5], surface quality becomes a very important factor of the measurement chain.

The aspects of an AUT thickness mapping inspection that are difficult to control during the test are those that are related to the varying and sometimes rapidly changing conditions of the area being scanned. Front surface quality plays an important role to ultrasonic wave transmission and mode conversion at the interface for the “0” point definition and the actual measurement accuracy. Existence of surface coating of any kind may complicate matters for the front-wall echo. Since an AUT system may move at some considerable distance from the operator[6] with distances of 20-40m easily attainable, the surface condition cannot be assessed for the entire are to be scanned and scaling and contaminants may exist that cannot be detected or removed. These may cause significant Non-Relevant Indications (NRI) in the data which must be evaluated and possibly removed. This can prove a difficult task without the right tools.

Although this is not a detailed discussion about the challenges faced by an automated ultrasonic system for large scale thickness mapping, it is immediately evident that, unlike manual UT measurements where the operator can control most of the conditions affecting the measurement, AUT has to cope with situations that are not controllable during the test, or it is not economical to control them. This is where the modern large data capacity systems are important that can store volumes of data which can be re-processed later to achieve better data quality and accuracy.

The volume of the data requires new management techniques and the traditional data logger is not sufficient. Modern software used special digital file formats to store the large amount of information and be able to process it fast. The speed at which information can be extracted, re-processed and displayed from a software is becoming increasingly important as file sizes increase.

## Reflections Measurement Strategy: A novel technique

The “Ultrasonic Imaging and Analysis” (UTIA) software[2] which is designed for re-processing thickness, amplitude and A-Scan data from NDT Automation Large Structure Inspection (LSI) systems[6], and implements Reflection Measurement Strategy as an alternative to the traditional “Gate” technique, as a means to solve problems associated with the varying surface and test conditions.

Although very robust, easy to understand and well known the Gate technique has a number of sort comings. These have to do with the relatively rigid nature of the measurement. The gate is fixed size and it can therefore measure only in the prescribed range. Although this may be useful for flaw detection and manually performed thickness gauging applications, it leaves some margin for improvements in large scale thickness mapping where large thickness variations may be observed. In addition modern AUT systems can traverse parts of a structure that may have significantly different nominal thicknesses. Although this can be addressed by changing the hardware and Gate setup of the system for each section it requires time, additional calibrations for each new set of settings and does not address large variations within the same section from normal corrosion, erosion or pitting. In addition the traditional Gate technique does not take into account changes in the front-wall echo quality which may vary due to the changing surface conditions mentioned previously. Most important, traditional Gate technique, has limited near surface resolution, due to interferences and confusion of front wall echo indications.

The UTIA software proposes a completely new way of extracting thickness information from an A-Scan, trying to overcome the problems of the traditional Gate technique where it is needed.

This technique is termed “Reflections” and the detection of thickness relies on the detection of the various reflections of the front-wall, back-wall and any other reflector above a certain threshold. Several of the concepts behind this technique are an adapted migration from Acoustic Emission feature extraction[7]. In this manner the measurement is not confined to the gate width (a gate does not even exist in this concept) but instead it is equivalent to an adaptive gate that can span the entire A-Scan time range or be as small as necessary for low thicknesses within the section.

The application of this technique has proven useful where pitting or large variations of thickness are observed. In addition it has been able to improve drastically the Non Relevant Indications when front-wall conditions are such that generate problems to the traditional Gate technique.

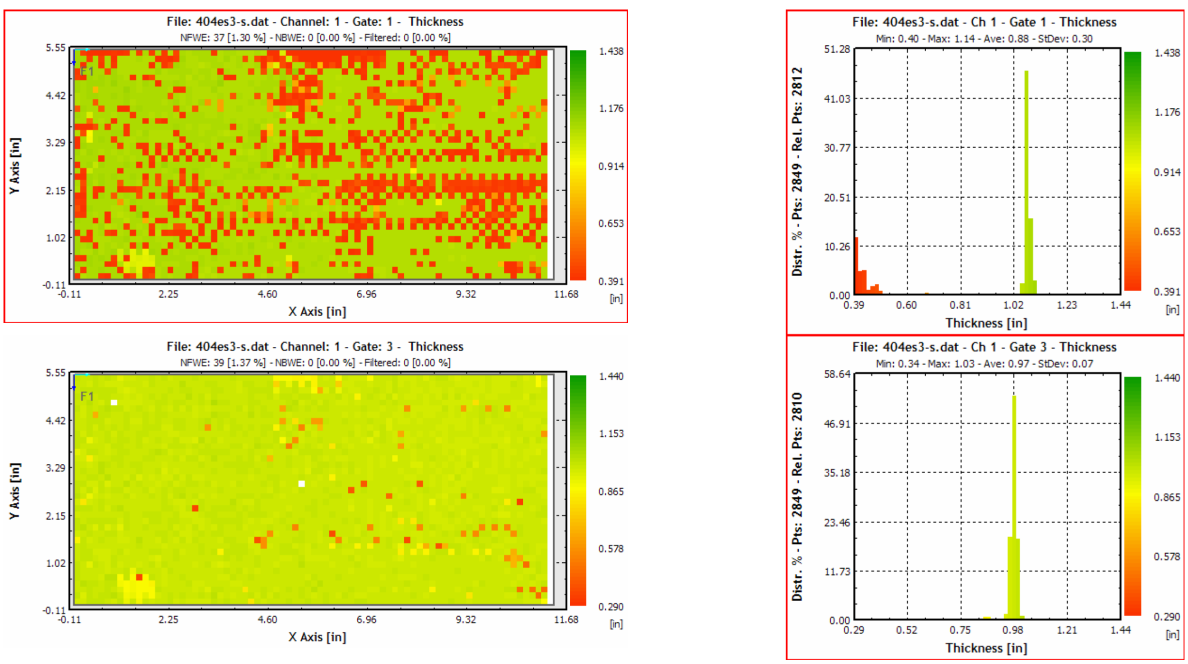



Figure 1. Example of the use of the Reflections strategy. The large number of NRI (red) in the top picture is not there when using the “Reflections” technique for thickness measurement (bottom picture). The respective histogram of thickness distribution is presented next to each C-Scan.

An example is shown in Figure 1 where the surface quality caused a lot of Non Relevant Indications (NRI) to appear with the Gate used. The use of the Reflections strategy drastically reduced the NRI and at the same time made some meaningful indications stand out (e.g. reduced thickness area bottom left). The amount of NRI can also be observed in the data statistical distribution. The actual average thickness was also reduced slightly. This was due to the smaller effect that the front-wall condition has on the accuracy of the measurement.

Re-processing data in this manner is fast on modern computers and it can be applied to large scale tests with hundreds of thousands measurements and not only to single scans with only a few thousand points. With proper knowledge and understanding of the technique the results can be a significant improvement over existing techniques.

## Data Management and Presentation for Massive Corrosion Mapping Tests

As previously mentioned, data volumes can be significant thus requiring separate post-processing software. An important task is, apart from re-processing the data to improve the measurement quality, the quality of the data presentation.

It is interesting to put forward a new concept for data quality which is defined by the data presentation quality and not only by the strict physical meaning which involves proper calibration and correct use of equipment. For example, it would be difficult and time consuming to make conclusions for even a 3000 thickness readings test if the data are reviewed as numbers in a table. The same would be impossible for the example shown in Figure 7 (contains more than 70,000 data point measurements). Therefore it is important to have a meaningful way to present/communicate the data. In this respect, and in addition to A-Scan re-processing, special software can perform other tasks to further improve data quality via data presentation techniques.

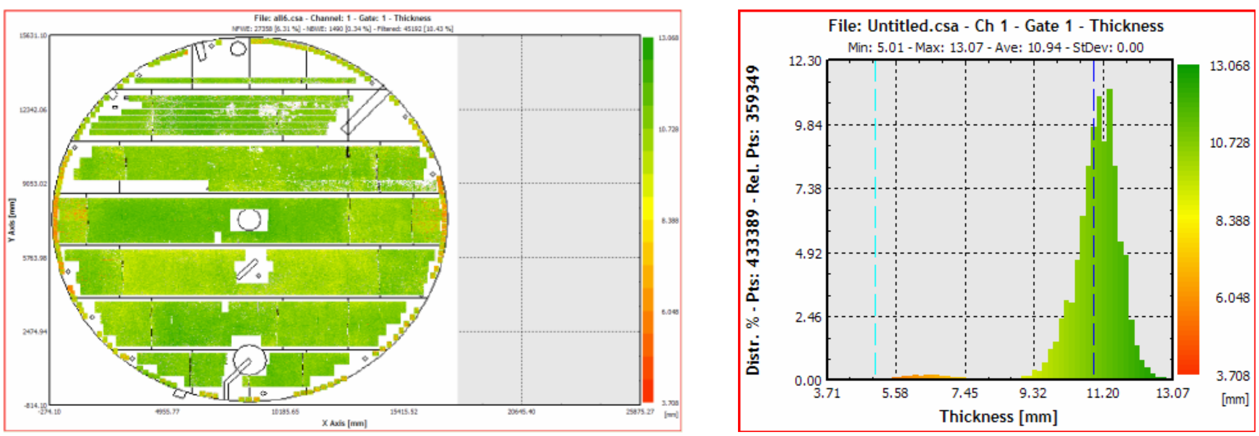



Figure 3. Tank floor composite scan. More than 200 individual scans were used to produce the composite image of more than 438,000 measurements.

Scanning large areas requires a large number of individual scans to be performed. To present the data in a meaningful manner the individual scans have to be arranged in a way so as to represent the physical object measured. This can prove a complicated task as any structure in the industry is rather complex. In addition when stitching together many scans, statistics of certain areas can be produced and the picture conveyed contains a lot of information and is easy to understand. In Figure 3 the composite scan of an entire atmospheric tank floor is presented. There are more than 200 individual scans that compose the image shown. In total more than 438,000 measurements were taken with an NDT Automation LSI digital ultrasonic C-Scan system[6] with 5x5mm step while scanning the annular ring area, and 10x20mm step where indications in the floor were

found and 20x40mm step resolution for the remaining floor scanning. From the composite C-Scan (Figure 3) it is immediately obvious that thinned areas exist at the tank circumference while the majority of the tank floor is near nominal. Using the tools provided in the UTIA software, statistics of the thinned areas were also provided thus giving a complete and detailed picture of the floor condition. This amount of information would be impossible to present in a compact and meaningful manner without the tools provided in modern post-processing software.
In addition local detailed analysis can also be performed and presented. In a test similar to the one presented above a tank's annular plates were scanned. The results were again presented as a composite image and statistical analysis was also done. Local thinning was observed near the wall which needed further local analysis. Using the Clustering algorithm in UTIA low thickness areas were automatically recognized and their statistics calculated and reported in tabular format. Again the information conveyed is very compact and easy to assess.

| Cluster ID | Area ($mm^2$) | Min Thick. | Ave Thick. |
|---|---|---|---|
| 1 | 348 | 5.61 | 7.71 |
| 2 | 280 | 6.93 | 8.13 |
| 3 | 84 | 7.27 | 8.38 |
| 4 | 260 | 4.08 | 7.79 |
| 5 | 120 | 4.04 | 7.65 |
| 6 | 96 | 4.25 | 8.40 |
| 7 | 168 | 7.48 | 8.24 |
| 8 | 448 | 5.36 | 7.32 |
| 9 | 272 | 7.48 | 8.43 |
| 10 | 120 | 6.51 | 7.84 |
| 11 | 336 | 4.04 | 6.84 |
| 12 | 96 | 7.44 | 8.29 |
| 13 | 136 | 6.04 | 7.24 |
| 14 | 144 | 5.95 | 7.32 |
| 15 | 216 | 5.06 | 6.88 |
| 16 | 272 | 5.78 | 7.12 |
| 17 | 104 | 7.48 | 8.25 |
| 18 | 176 | 4.17 | 7.22 |

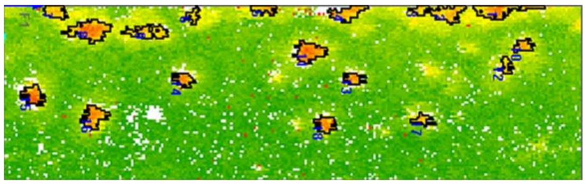


Figure 4. Statistical analysis and local scan presentation. Clustering was used to automatically find and report areas of increased thinning in tank annular plates.

## Data Treatment

In several cases varying test conditions may necessitate data re-processing in an attempt to improve data quality. In addition varying thicknesses would require different settings for each part of a structure. A typical case is the vertical scanning of atmospheric tank walls. Vertical scans are taken which span the entire height of the tank and thus several different plate thicknesses.

As tanks are painted there is a need for through paint thickness calculation i.e. measurement of the metal thickness only. The challenges that such a test posses to an automated UT system are to achieve good signal in varying surface and material condition, removing the thickness of the paint from the data, the treatment of non-relevant indications (NRI), composition of various C-Scans to produce a vertical scan in its entirety, the C-Scan presentation in a meaningful, color-coded universal color scale taking into account the different nominal thicknesses.

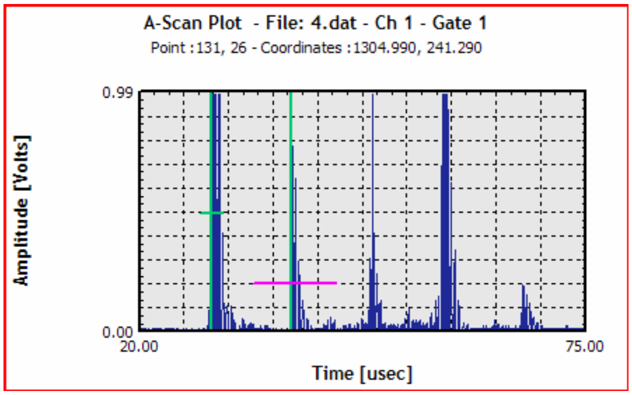



Figure 5: Recording second back wall echo for paint thickness removal.

In a specific tank case the A-Scan width was set so as to record the second back wall echo for paint thickness removal calculations in post-processing the data. Due to the large variation in expected thicknesses a DAC curve was built manually to 80% screen height.
The data collected included RF (A-Scan) storage to be able to re-compute TOF (Time of Flight) and Amplitude measurements. This was necessary as it is nearly impossible to get high quality data real-time for such detailed analysis in actual conditions. The data will almost always require post-test analysis.
The RF saved were used to re-compute TOF and Amplitude with the Ultrasonic Imaging and Analysis (UTIA) software by making necessary adjustments to measurement parameters to avoid the original NRI and false measurements and complete a set of data to use for the evaluation.
In real-time, without a priory knowledge of the area to be scanned and its particular conditions, it is impossible for an operator to setup the parameters so as to achieve the best possible scan, and it is not economical to inspect the data after scanning and re-scan the area adjusting parameters.
During this particular test the data required to make through-paint thickness measurements was from defined Gates 1 and 2. The acquisition software has the capability of making the computation from the two Gates real-time. The post-processing of the data showed that the results could be drastically improved.

In general Gate 1 data did not show any significant need for processing. Gate 2, monitoring the second back wall reflection, suffered from NRI and false measurements due to the varying conditions during the test. In the example scan shown in Figure 6 the raw and processed data are shown. The original data have a lot of missed data points and NRI. The original data report 56.2% data points measured with approximately 8% NRI. The minor adjustments and advanced processing capabilities of the UTIA software have provided the operator with a final 79.1% data points measured (a relative improvement of 40%) with 6.5% NRI (a relative improvement of 23%). The change in data statistics is also evident since NRI, and false measurements do not affect the average values in the scan, and statistics are more meaningful.
This data was further used to make the through paint computation. The end result was a drastic improvement on the reported data over the actual data collected on the field and a lot of field time saved thus making the test more economical and faster.

| Data Set (Scan) | Valid Data Points Measured | | NRI and false measurements (estimated from statistical distribution) | |
|---|---|---|---|---|
| | Raw | Processed | Raw | Processed |
| 1 | 99.9% | Not Processed | <1% | Not Processed |
| 2 | 97.4% | Not Processed | 3% | Not Processed |
| 3 | 98.9% | Not Processed | <1% | Not Processed |
| 4 | 99.5% | 98.5% | 47% | <1% |
| 5 | 81.3% | 92.9% | 1.7% | 1.6% |
| 6 | 56.2% | 79.1% | 8% | 6.5% |
| 7 | 44.6% | 98.6% | 15% | <1% |

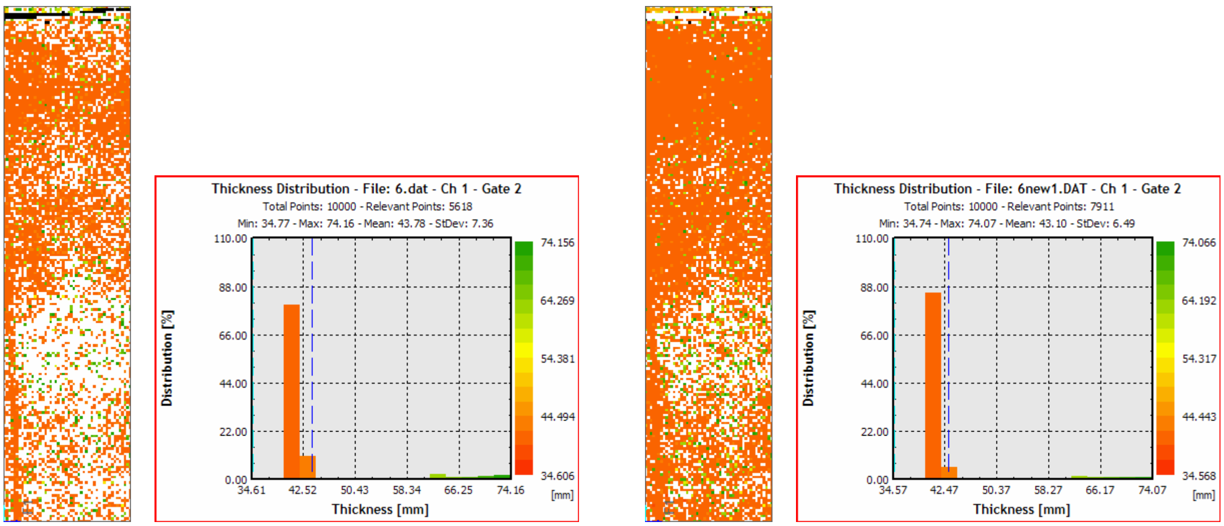
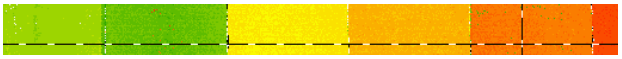
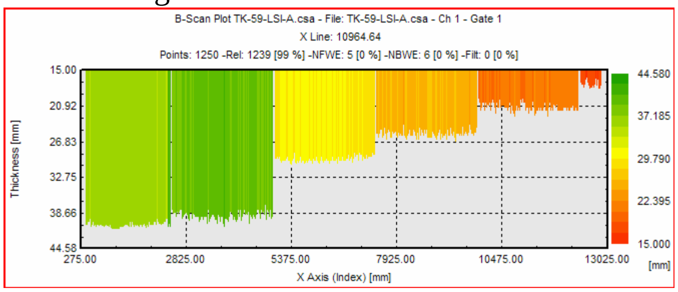


Figure 6: Raw Data (Top) and Processed Data (Bottom).

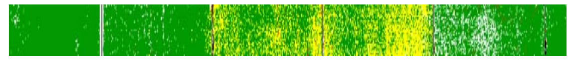
As previously mentioned the concept of data quality that is related to meaningful data presentation is important. In this example the processed data from data sets (C-Scans) 1 through 7 (see Table) are combined to produce the composite C-Scan image shown in Figure 7 with its corresponding B-Scan. The composite C-Scan is presented in two different manners to show how data presentation can affect data interpretation. In Figure 7a (top left) the data are shown with a continuous color (thickness) scale where the difference in thickness of adjacent plates is evident. In this case there does not seem to be an area with visible material loss. In Figure 7b (top right) the same C-Scan is shown using a color (thickness) scaling that takes into account the nominal-caution-reject limits for each plate and thus presents the data in relative color scaling. In this case we can see that a significant area in the 3rd and 4th plates show thinning below the caution limit.



C-Scan image.




B-Scan of above C-Scan at the dashed line.



C-Scan image.


Thickness/Color scale.

Figure 7. Example of different representation of data

## Conclusions

The present work has outlined the various challenges that modern AUT tests are faced with. Needless to say that operator training is important in order that appropriate training allows them to provide solutions for a number of these challenges. This would only work as far as the AUT system is concerned and physical conditions are more difficult and sometimes impossible to control (e.g. surface condition). This is where special post-processing software can provide a significant tool. This work has also shown how important the use of such tools is for the successful completion of AUT tests. Coupled with new measurement techniques that are designed to cope with such problems, good data management, fast processing and data presentation, large AUT tests can prove the only solution in many cases.

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